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DETECTION AND LOCATION OF FAULTS IN THREE PHASE UNDER GROUND POWER CABLE USING WAVELET TRANSFORM

D.Prabhavathi[1], K. Prakasam[2] Dr.M.Surya Kalavathi[3] Dr.B.Ravindra Nath Reddy[4]

[1]Sri Sivani College of Engineering Srikakulam, Andhra Pradesh, India

[2]Sri Sivani Institute of Tech Srikakulam, Andhra Pradesh, India

[3]JNTUH Hyderbad, Prof Dept of EEE, Kukatpalli, Hyderbad,

[4]Executive Engineering, JNTUH, kukatpalli, Hyderabad,

ABSTRACT

Power system fault location and identification of the different faults on a underground power cable system for quick & reliable operation of protection scheme. Fault location estimation is very important issue in power system in order to clear faults quickly & restore power supply but the location of fault can be analyzed only with wavelet transform. Wavelet transform, which is very fast and sensitive to noise, is used to extract transients in the line currents for fault detection. The de-noising process rejects noise by thresholding in the wavelet domain and also improves the quality of the signal. Three wavelet functions ("db", "coif" and "sym") and three different thresh holding methods are “Rigsure”, “Sqtwolog” and “Minimax” used to de-noise the noise signal. Thresholding rule for three different performance measures were considered to select the appropriate wavelet function to efficient noise removal methods such as, signal-to-noise ratio (SNR), mean square error (MSE), and smoothing ratio, it can be a good way to evaluate the equality of wavelet threshold de-noising. The results show that the wavelet transform can achieve excellent results in signal de-noising; de-noised signal using soft-threshold method is smoother and Soft-threshold method is more suitable. At the end, I used the classification of wavelet threshold analysis for signal decomposition to monitor some of the faults (e.g. L-G Fault and LLL-G Fault,) in the underground power cable system. ATP/EMTP simulation results are presented showing the selection of proper threshold value for fault detection also applied the wavelet Toolbox for use with MATLAB to estimate the location of the fault.

Keyword: Wavelet Transform, Discrete Wavelet Transform, Signal De-Noising, Transmission Line Faults

I. INTRODUCTION

In the modern electrical power systems of transmission and distribution systems, underground cable is used largely in urban areas and compared to overhead lines, fewer faults occur in underground cables. However if faults occur, it's difficult to repair and locate the fault. Faults that could occur on underground cables networks are single phase-to-earth (LG) fault; double phase-to-earth (LLG) fault, phase-to-phase (LL) fault and three phase-to-earths (LLLG) fault [1]. The single line to earth fault is the most common fault type and occurs most frequently. Fault detection and location based on the fault induced current or voltage travelling waves has been studied for years together. In all these techniques, the location of the fault is determined using the high frequency transients. The main idea behind these techniques is based on the reverberation of the fault generated travelling waves in the faulty system. Fault location based on the travelling waves can generally be categorized into two: single-ended and double ended. For single-ended, the current or voltage signals are measured at one end of the line and fault location relies on the analysis of these signals to detect the reflections that occur between the measuring point and the fault. For the double-ended method, the time of arrival of the first fault generated signals are measured at both ends of the lines using synchronized timers. The double-ended method does not require multiple reflections of the signals. However, single-ended location is preferred as it only requires one unit per line and a communication link is not necessary. This paper presents a wavelet technique have been applied that can extract the high frequency fault signals for determination of cable fault and location. The technique applied here determines the fault position by measuring the travelling time of the high frequency current signals. In this paper 11kV distribution cable is modeled using ATP/EMTP Simulink software, the response for the different fault(LG and LLLG) was examined and then wavelet transform Db5 is applied with band pass filter to derive the exact location of the fault.

II. WAVELET TRANSFORM

Wavelet transform is much like the Fourier transforms, however with one important difference: it allows time localization of different frequency components of a given signal. Windowed Fourier transform also partially achieves this same goal, but with a limitation of using a fixed width windowing function. In the case of wavelet transform, the analyzing functions, which are called wavelets, will adjust their time widths to their frequency in such a way that, higher frequency wavelet will be narrow and lower frequency ones will be broader. So this property of multi resolution is particularly useful for analyzing fault transients which contain localized high frequency components superposed on power frequency signals. Thus, wavelet transform is better suited for analysis of signals containing short lived high frequency disturbances superposed on lower frequency continuous waveform by virtual of this zoom in capability [2]. Given a function f (t), its continuous wavelet transform (WT) will be calculated as follows:

$$WT(f,a,b) = \frac{1}{\sqrt{a}} \int f(t)\, \psi * \frac{(t-b)}{a} dt \tag{2.1}$$

Where, a and b are the scaling (dilation) and translation (time shift) constants respectively, and ψ is the wavelet function (mother wavelet).

The continuous wavelet transform (CWT) computes the inner product of a signal (t), with translated and dilated versions of an analyzing wavelet, ψ (t) the definition of the CWT is:

$$C(a,b;f(t),\psi(t)) = \int_{-\infty}^{\infty} f(t) \frac{1}{\sqrt{a}}\, \psi * \frac{(t-b)}{a} dt \tag{2.2}$$

You can also interpret the CWT as a frequency-based filtering of the signal by rewriting the CWT as an inverse Fourier transform.

$$C(a,b;f(t),\psi(t))=\frac{1}{2\pi}\int_{-\infty}^{\infty}\hat{f}(\omega)\ \sqrt{a}\ \hat{\psi}(\omega)(aw))*e^{jab}\omega \tag{2.3}$$

Where f(ω)and $\psi(\omega)$ are the Fourier transforms of the signal and the wavelet.

From the preceding equations, you can see that stretching a wavelet in time causes its support in the frequency domain to shrink. In addition to shrinking the frequency support, the center frequency of the wavelet shifts towards lower frequencies. This depicts the CWT as a band pass filtering of the input signal. CWT coefficients at lower scales represent energy in the input signal at higher frequencies, while CWT coefficients at higher scales represent energy in the input signal at lower frequencies. However, unlike Fourier band pass filtering, the width of the band pass filter in the CWT is inversely proportional to scale. The width of the CWT *filters* decreases with increasing scale. This follows from the *uncertainty* relationships between the time and frequency support of a signal: the broader the support of a signal in time, the narrower its support in frequency. The converse relationship also holds.

In the wavelet transform, the scale or dilation operation is defined to preserve energy. To preserve energy while shrinking the frequency support requires that the peak energy level increases. The *quality factor* or *Q factor* of a filter is the ratio of its peak energy to bandwidth. Because shrinking or stretching the frequency support of a wavelet results in commensurate increases or decreases in its peak energy, wavelets are often referred to as constant-Q filters.

The driving force behind wavelet transforms (WTs) is to overcome the disadvantages embedded in short time Fourier transform (STFT), which provides constant resolution for all frequencies since it uses the same window for the analysis of the inspected signal x (t). On the contrary, WTs use multi-resolution, that is, they use different window functions to analyse different frequency bands of the signal x (t). Different window functions ψ(s,b,t);which are also called son wavelets, can be generated by dilation or compression of a mother wavelet ψ(t) , at different time frame. A scale is the inverse of its corresponding frequency. WTs can be categorised as discrete WTs or continuous WTs. For vibration-based fault diagnosis, usually continuous WTs are employed. A continuous type of wavelet transform (CWT) that is applied to the signal x (t) can be defined as,

$$w(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} f(t)\psi\left(\frac{t-b}{a}\right)dt \tag{3.1}$$

Where

a is the dilation factor,

b is the translation factor and

ψ (t) is the mother wavelet.

$1/\sqrt{a}$ is an energy normalization term that makes wavelets of different scale has the same amount of energy.

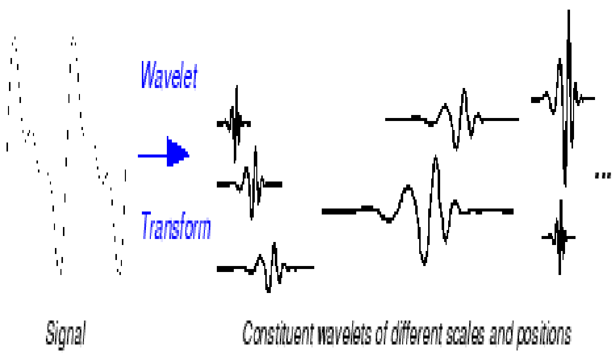
III. DISCRETE WAVELET TRANSFORM FOR FAULT PARAMETERIZATION

In this study, the line current signals are used as the input signals of the wavelet analysis. The DWT, using a Daubechies-4 wavelet (db4), performed better at identifying the start and end of a disturbance. The Daubechies wavelet is very well suited for identifying short-time, high frequency transients, as well as low frequency behavior over longer periods of time. In both cases the signals are nonperiodic or non-stationary [61]. The fault transients of the study cases are analyzed through

discrete wavelet transform at levels one to five. Both approximation and details information related fault current are extracted from the original signal with the multi-resolution analysis. When a fault occurs in the cable, it can be seen that variations within the decomposition coefficient of the current signals contain useful fault signatures. FIGURE 5-15 shows the DWT detailed coefficients at level 1 to level 5 for a particular type of fault studied in the work. Nature of the plot of detailed coefficients at level 1 shows a sharp spike corresponding to the fault initiation. According to DWT theory, this spike represents the highest frequency available in the fault signal. It is however, not wise to try to identify fault based on this spike only since such spikes will occur every time there is a sudden change in the cable current signal [56]. This will thus not be able to clearly differentiate between faults of different types and at different locations. Like the Fourier transform, the continuous wavelet transform (CWT) uses inner products to measure the similarity between a signal and an analyzing function. In the Fourier transform, the analyzing functions are complex exponentials; $e^{j\omega t}$ The resulting transform is a function of a single variable, ω. In the short-time Fourier transform, the analyzing functions are windowed complex exponentials, W (t) $e^{j\omega t}$and the result in a function of two variables. The STFT coefficients, F(ω,τ) represent the match between the signal and a sinusoid with angular frequency ω in an interval of a specified length centered at τ.In the CWT, the analyzing function is a wavelet, ψ. The CWT compares the signal to shifted and compressed or stretched versions of a wavelet. Stretching or compressing a function is collectively referred to as dilation or scaling and corresponds to the physical notion of *scale*. By comparing the signal to the wavelet at various scales and positions, you obtain a function of two variables. The two-dimensional representation of a one-dimensional signal is redundant. If the wavelet is complex-valued, the CWT is a complex-valued function of scale and position. If the signal is real-valued, the CWT is a real-valued function of scale and position. For a scale parameter, a>0, and position, *b*, the CWT is:

$$c(a,b;f(t),\psi(t))=\int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{a}}\,\psi * \frac{(t-b)}{a}dt \tag{3.2}$$

where * denotes the complex conjugate. Not only do the values of scale and position affect the CWT coefficients, the choice of wavelet also affects the values of the coefficients. By continuously varying the values of the scale parameter, *a*, and the position parameter, *b*, you obtain the *CWT Coefficients C(a,b)*. Note that for convenience, the dependence of the CWT coefficients on the function and analyzing wavelet has been suppressed. Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constitute wavelets of the original signal.



There are many different admissible wavelets that can be used in the CWT. While it may seem confusing that there are so many choices for the analyzing wavelet, it is actually a strength of wavelet analysis. Depending on what signal features you are trying to detect, you are free to select a wavelet that facilitates your detection of that feature. For example, if you are trying to detect abrupt

discontinuities in your signal, you may choose one wavelet. On the other hand, if you are interesting in finding oscillations with smooth onsets and offsets, you are free to choose a wavelet that more closely matches that behavior.

IV. IDENTIFICATION AND LOCATION OF FAULTS

A. Transient Signals

By comparing the transient signals at all phases the classification of fault can be made .If the transient signal appears at only one phase then the fault is single line to ground fault The transient signals generated by the fault is no stationary and is of wide band of frequency, when fault occurs in the network, the generated transient signals travels in the network. On the arrival at a discontinuity position, the transient wave will be partly reflected and the remainder is incident to the line impedance. The transient reflected from the end of the line travels back to the fault point where another reflection and incident occur due to the discontinuity of impedance. To capture these transient signals wavelet analysis can be used. The fault location can be carried out by comparing the aerial mode wavelet coefficient to determine the time instant when the energy of the signal reaches its peak value. The distance between the fault point and the bus of the faulted branch is calculated as follows consider a three phase cable line of length X connected between bus A and bus B, with a characteristic impedance Zc and traveling wave velocity of v. If a fault occurs at a distance X_2 from bus A, this will appear as an abrupt injection at the fault point. This injection will travel like a wave "surge" along the line in both directions and will continue to bounce back and forth between fault point, and the two terminal buses until the post-fault steady state is reached. The distance to the fault point can be calculated bu using travelling wave theory. Let t_1 and t_2 corresponds to the times at which the modal signals wavelet coefficients in scale 1, show their initial peaks for signals recorder at bus A and bus B. the delay between the fault detection times at the two ends is $t_l - t_2$ be determined. When td is determined we could obtain the fault location from bus A According to:

$$X_2 = X- (t_1-t_2)\ V/2 \qquad (4.1)$$

Or from bus B

$$X_1 = X - (t_2- t_1)\ V/2 \qquad (4.2)$$

The v is assumed to be 1.8182x105 miles/sec, Sampling time is 10 us and the total line length is 100km. Where X_1 and X_2 is the distance to the fault, td is the time difference between two consecutive peaks of the wavelet transform coefficients of the recorded current and v is the wave propagation velocity.

B. Fault Detection and Location

By comparing the transient signals at all phases the classification of fault can be made .If the transient signal appears at only one phase then the fault is single line to ground fault The transient signals generated by the fault is no stationary and is of wide band of frequency, when fault occurs in the network, the generated transient signals travels in the network. On the arrival at a discontinuity position, the transient wave will be partly reflected and the remainder is incident to the line impedance. The transient reflected from the end of the line travels back to the fault point where another reflection and incident occur due to the discontinuity of impedance. To capture these transient signals wavelet analysis can be used. The fault location can be carried out by comparing the aerial mode wavelet coefficient to determine the time instant when the energy of the signal reaches

its peak value. The distance between the fault point and the bus of the faulted branch will be given by

$$D = \frac{v\ x\ t_d}{2} \qquad (4.3)$$

Where D is the distance to the fault, td is the time difference between two consecutive peaks of the wavelet transform coefficients of the recorded current and v is the wave propagation velocity of the aerial mode.

B. Modeling of Cable

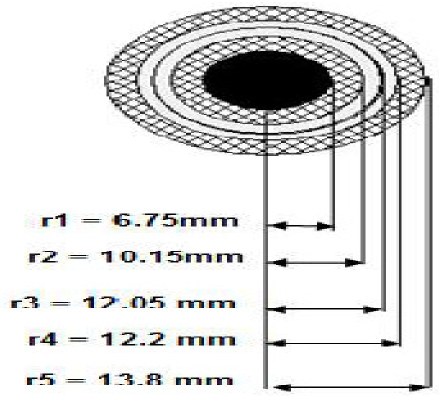


Figure4.1. Three phase cable model

C. Specification of cable

Radius (mm)	r1= 6.75, r2 = 10.15, r3 = 12.05 r4 = 12.2, r5 = 13.8
Core conductor	c = 1.7 E-8Ω.m , µc = 1.0
Insulation	µi = 1.0 , €i =2.7
Sheath	sh = 2.5 E-8Ω.m , µsh = 1.0

D. Specifications of load

Load	2 MVA
Resistance (R)	71.157 Ω
Inductance (L)	365.475mH

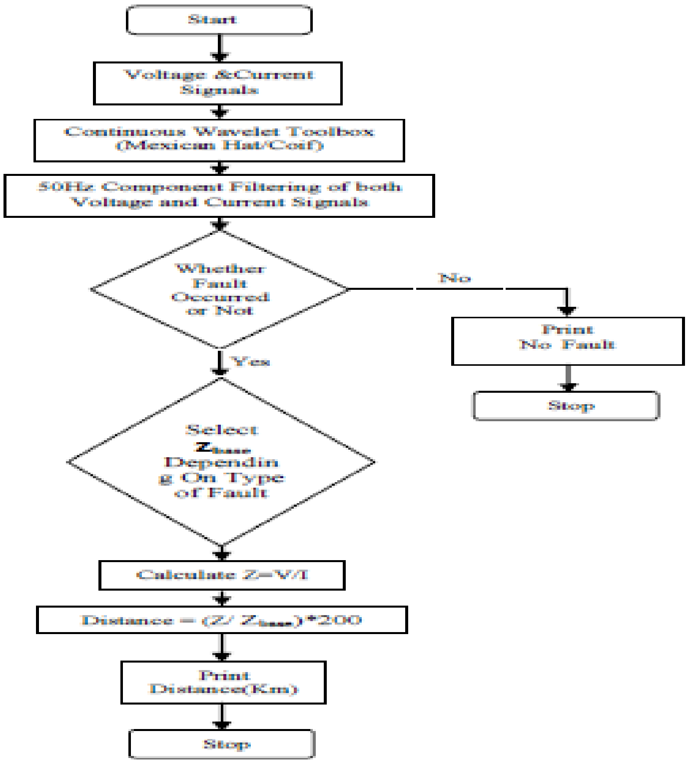


Figure4.2. Flowchart of the proposed algorithm is

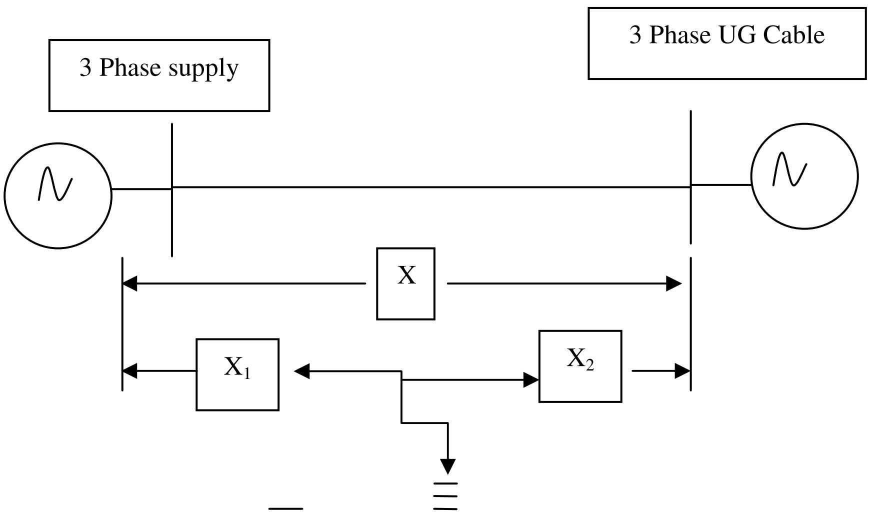


Fig.4.3. Three - Phase underground cable Transmission line

Table 1

Fault	Exact Distance	Wavelet based	Error in percentage
LG	1.5	1.9	-6.66
LLLG	1.5	2.05	-8.5

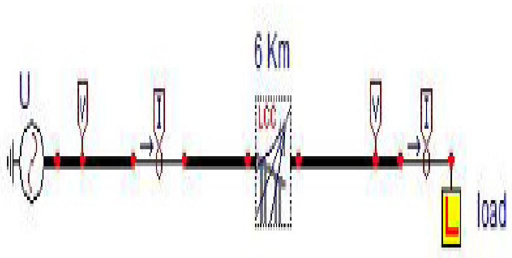


Figure 4.4 Single line diagrams at normal condition (No fault condition)

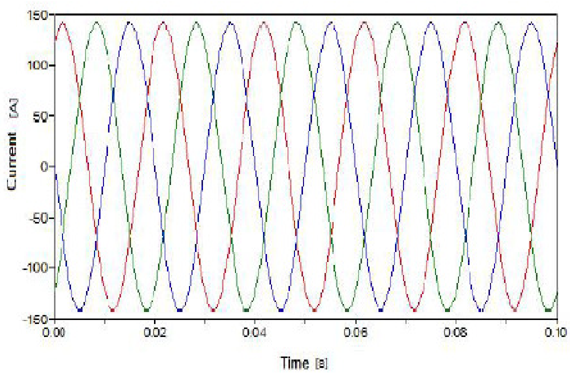


Figure 4.5 Current waveforms at no fault (normal conditions)

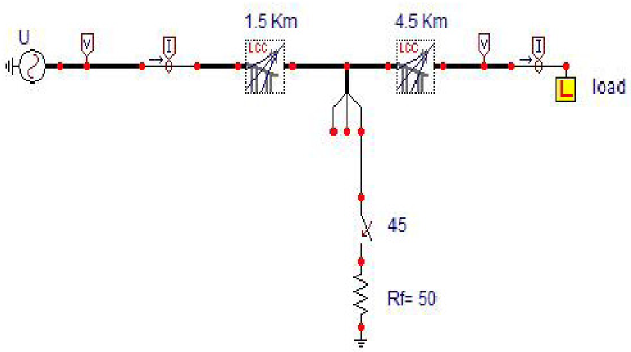


Figure 4.6 single line diagram of at no fault (normal conditions)

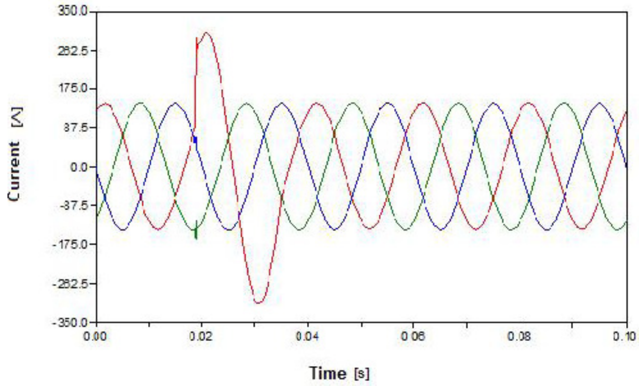


Figure 4.7 Current waveform at single line to ground fault. (With fault resistance=50Ω, Inception Angle =45deg and fault location=1.5 Km).

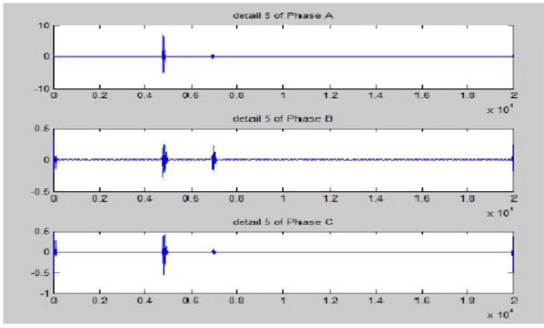


Figure 4.8 level 5 detailed coefficients of Single Line to Ground Fault case

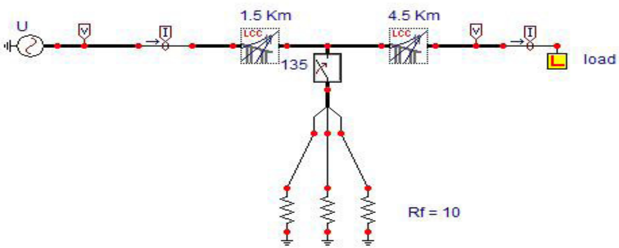


Figure 4.9 Single line diagram of three phases to ground fault. Location=1.5 Km).

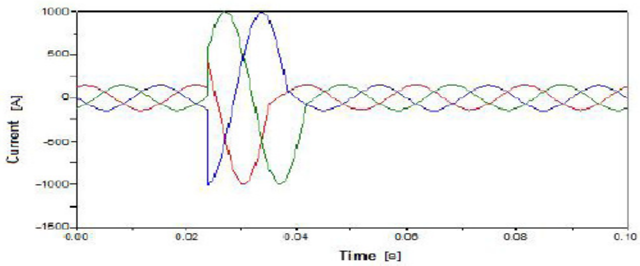


Figure 4.10 Current waveforms at three phase to ground fault (with fault resistance=10Ω, Inception Angle =135 deg and fault Location=1.5 Km).

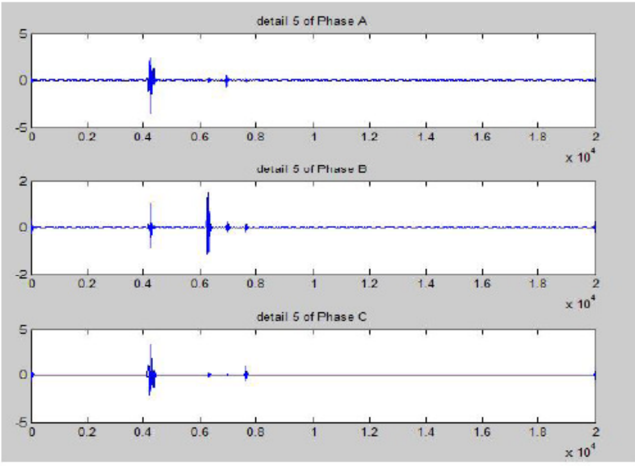


Figure 4.11 level 5 detailed coefficients of Three Phase to Ground Fault case

V. CONCLUSIONS

Wavelet transform effectively acts as a band pass filter which extracts a band of high frequency transient current signals from the faulted cable. The total length of the cable considered is 6km. Results from simulations are obtained with 800 Hz sampling rate and with Wavelet transform of db5 level the travelling wave velocity of the signals in the 11 kV underground cable system is 1.8182×10^5 km/s, and sampling time of 10µs is used. Fig 1 depicts the single line diagram of the simulated system which is 11KV, 50Hz, 6km underground power cable. In this paper the authors modeled the three phase underground cable using ATP/EMTP software and selected LG fault conditions in the underground cables and then LLLG fault is selected First LG fault is simulated at a distance of 1.5km the results are shown in figures 4.7 and the wavelet result is shown in figure 4.8 with the application of Db5.Then three phase fault is simulated at 1.5km and the wavelet is applied for the same fault and the result is shown 4.10 and 4.11.The % of fault location error is defined as %error = (Estimated Distance – Exact Distance)/(Total Cable Length)X 100,Where total length of the Cable is 6Km.The fault created at 1.5km and the error results obtained by wavelet transform are as shown in table 1.The solution obtained in this paper can helps the research scholars and the authors for further work as this paper gives the exact results. However by implementing other methodologies somemore work can be done for better results.

VI. ACKNOWLEDGEMENTS

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AUTHOR PROFILE

D.PRABHAVATHI Born in 1976 August 27, her B.Tech degree from K.S.R.M College of Engineering, Kadapa , S.V University, and M.Tech degree from S.V university in the year 2003.She has specialized in Power Systems, High Voltage Engineering. Her research interests include Simulation studies on faults identification in UG cable of LT and HT. Fuzzy logic, High Voltage Engineering, Power Quality, FACTS Controllers; she has 14 years of experience. She has guided 28 M.Tech Projects and 65 Batch projects in various areas of engineering. She has published 18 international journals, 01 interr national conference and 08 national conferences. She is presently working as Prof and H.O.D of Dept of E.E.E, Sri Sivani Institute of Technology, Srikakulam Andhrapradesh ,INDIA

K.PRAKASAM, Born in 1973 April 20, his B.Tech degree from KSRM College of Engineering S.V.Uuniversity in 1997 and M.Tech degree from S.V university in the year 2004. He has specialised in Power Systems, High Voltage Engineering and Control Systems. He has published 15 international journals, 01 international conference and 09 national conferences in various areas of research fields. His research interests include Simulation studies on Transients of different power system equipment. He has 17 years of experience. He is presently working as Prof and H.O.D of Dept of E.E.E, Sri Sivani College of Engineering, Srikakulam, Andhra Pradesh, INDIA.

Dr. **M. SURYA KALAVATHI**, Born on 8th July 1966, Obtained her B.Tech degree from S.V. U. in 1988 and M.Tech from S.V.U. in the year 1992. Obtained her doctoral degree from J.N.T.U, Hyderabad and Post Doctoral from CMU, USA. She is presently the Professor in the department of EEE, J.N.T.U.H College of Engineering J.N.T.U.H, Kukatpally, Hyderabad. Published 21 Research Papers and presently guiding many Ph.D. Scholars. She has specialized in Power Systems, High Voltage Engineering and Control Systems. Her research interests include Simulation studies on Transients of different power system equipment. She has 25 years of experience. She had awarded 4 no of PhDs from JNTU Hyderabad and Anantapur under her guidance. She has published many international and national journals as well as many international and national conferences. She has invited for various lectures in repudiated institutes in and around Andhra Pradesh and Telangana colleges.

BHUMANAPALLY.RAVINDHRANATH Reddy, Born on 3rd September, 1969. Got his B.Tech in Electrical & Electronics Engineering from the J.N.T.U. College of Engineering. Anantapur in the year 1991.Completed his M.Tech in Energy Systems in IPGSR of J.N.T.University Hyderabad in the year 1997. Obtained his doctoral degree from J.N.T.U.A,Anantapur University in the field of Electrical Power Systems. Published 25 Research Papers and presently guiding 6 Ph.D. Scholars. He is specialized in Power Systems, High Voltage Engineering and Control Systems. His research interests include Simulation studies on Transients of different power system equipment.